Atmospheric Physics I

- 2d. Determine the relationships between variables relating to pressure.

Force

- It is a push or pull capable of changing the state of motion of an object.
- Since a force has magnitude as well as direction, it is a vector quantity.
- Newton's second law of motion is a relationship between net force, acceleration and mass that describes the cause of a change of motion

$$\mathbf{F} = m\,\mathbf{a}$$

Force

- Newton's second law of motion; $F = m\ a$
  - Terms
    - m is the mass of the object
    - a is the acceleration of an object
  - Units: kg m/s^2 or Newton (N)

Force

- Variable relationships
  - Force is directly proportional to mass, when acceleration is constant.
    - Example 1: If the mass increases by a factor of 10, what will happen to the force? (It will also increase by a factor of 10 ↑**F** = ↑m **a**)
    - Example 2: If the mass decreases by a factor of 5, what will happen to the force? (It will also decrease by a factor of 5 ↓**F** = ↓m **a**)

Force

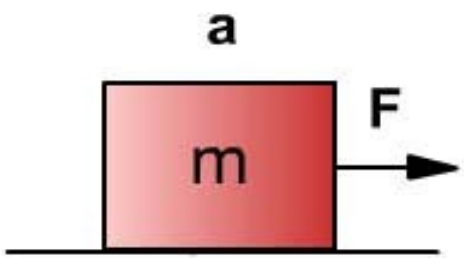
- Variable relationships
  - Force is directly proportional to acceleration, when mass is assumed constant.
    - Example 1: If the acceleration increases by a factor of 8, what will happen to the force? (It will also increase by a factor of 8 $\uparrow \mathbf{F} = m \uparrow \mathbf{a}$)
    - Example 2: If the acceleration decreases by half, what will happen to the force? (It will also decrease by half $\downarrow \mathbf{F} = m \downarrow \mathbf{a}$)

Force

- Examples of force.
  - How much force must be exerted on an object of mass “m” to double the acceleration?
  - Which has a greater force acting on it? Object A: a 2 kg object accelerating at 2 m/s^2 or Object B: a 6 kg object accelerating at 2 m/s^2?

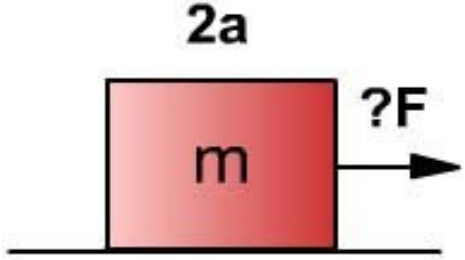
Force Example 1

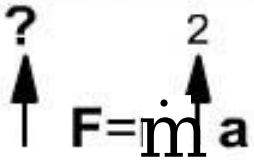
sinking air



F=ma

rising air





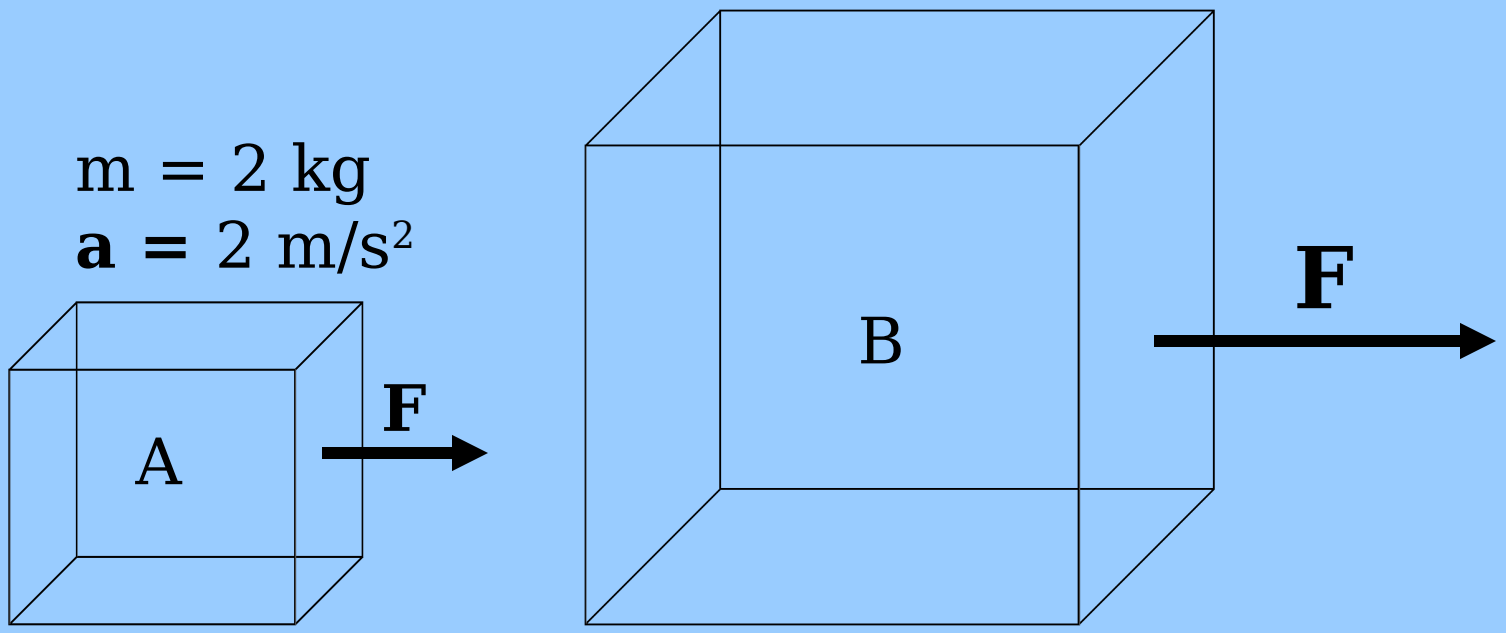
F=m a

? = 2

Force Example 2

m = 6 kg
a = 2 m/s²

m = 2 kg
a = 2 m/s²



F = m **a**
= (2 kg) (2 m/s²)
= 4 kg m/s²

$\uparrow \mathbf{F} = \dot{m} \uparrow \mathbf{a}$
= (6 kg) (2 m/s²)
= 12 kg m/s²

Force

- Examples of force.
  - Since Object B is 3 times more massive than object A, how does the force exerted by object A compare to that of by object B?

Weight

- Weight is a measure of the force of gravity on an object and this force can be calculated from Newton's second law of motion.
  - Equation $w = m g$
    - m is the mass of the object
    - g is the acceleration due to gravity
  - Units: Same as force (N)

Weight

- Variable relationships
  - Weight is only dependent upon the mass since gravity is constant. Weight is directly proportional to mass. (same as force)
  - If the mass increases, the weight increases.

$$\uparrow w = \uparrow m\,\dot{g}$$

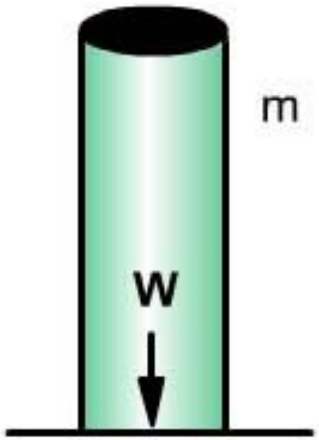
  - If the mass decreases, the weight decreases.

$$\downarrow w = \downarrow m\,\dot{g}$$

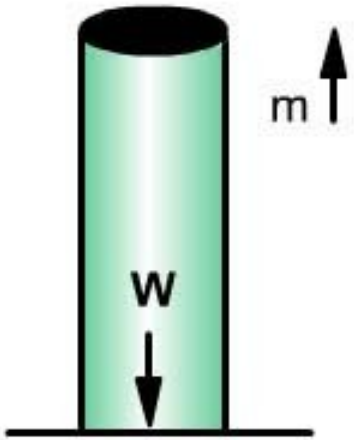
Weight

- The atmosphere exerts a force on the surface of the earth equal to its weight.
- Example: If the amount of mass in a column of atmosphere increases, what happens to the force (weight) exerted upon the earth's surface by the column?

Weight Example



$W = mg$



? $W = \uparrow mg$

$W = \uparrow mg$

Atmospheric pressure

- The weight of the atmosphere exerts a force over a unit area.
- This force, divided by the area, is called pressure

$$P = \frac{F}{A}$$

- As altitude increases, the weight of the atmosphere above a unit area decreases, therefore the pressure decreases.
- Pressure is a scalar quantity (has magnitude only).

Atmospheric pressure

- Units of pressure (mks system)
  - In the mks system, N/m^2 or a Pascal. (Pa)
  - More commonly used is the millibar, where 1 mb = 1 hPa = 100 Pa

Atmospheric pressure

- Variable relationships
  - Pressure is directly proportional to force, when area is assumed constant.
    - Example: When the force acting upon an object is doubled, what happens to the pressure? (Answer: pressure doubles)

$$\uparrow P = \frac{\uparrow F}{A} \qquad \frac{\downarrow F}{A} = \downarrow P$$

    - Example: A force of 10 N acting over 1 m^2 is decreased to 5 N. How does the pressure change? (Answer: pressure is cut in half))

Atmospheric pressure

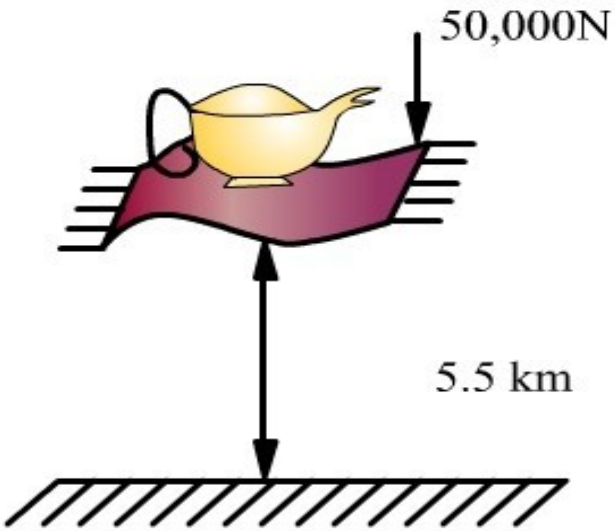
- Variable relationships
  - Pressure is inversely proportional to area, when force is constant.
    - Example: Which is greater and by how much? A: the pressure of a 30 N force exerted over 5 m^2 or B: a 30 N force over 15 m^2? (Hint:P =F/A)
    - Example: If the area over which a force acts is decreased by a factor of 5, what happens to the pressure? (Hint: ↑P = F/ ↓ A)

Atmospheric pressure

- Atmospheric pressure example
  - You fly a magic carpet of 1 m^2 in area to an altitude of 5.5 km MSL. The weight of the atmosphere above the carpet is 50,000 N. What is the atmospheric pressure at this level in millibars?
  - What is the pressure at the top of the atmosphere?

Magic Carpet Example

Calculating Pressure



$$P = \frac{F}{A} = \frac{w}{A}$$

$w = 50{,}000\text{N}$

$A = 1\text{m}^2$

$$P = \frac{50{,}000\text{N}}{1\text{m}^2}$$

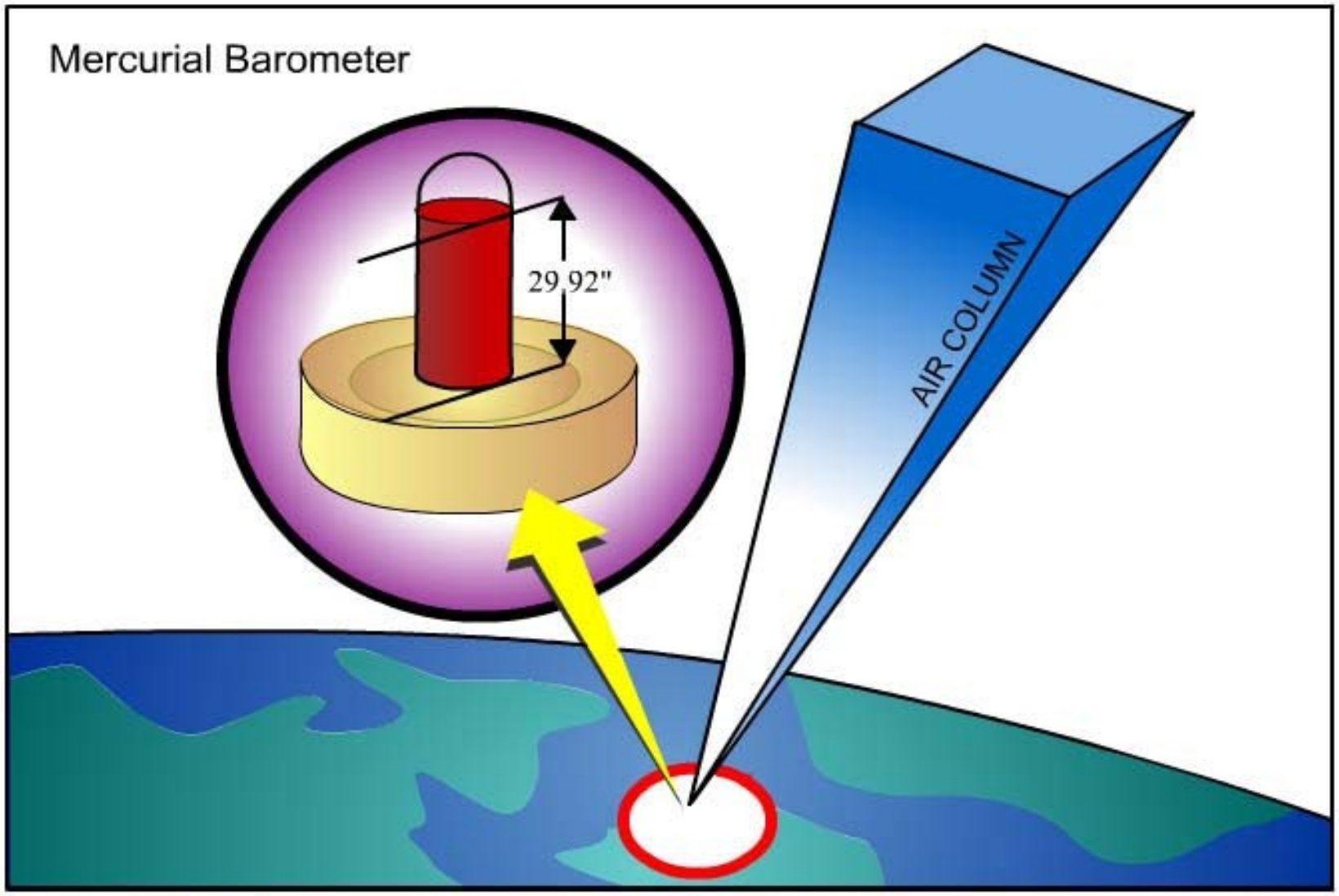
$= 50{,}000$ Pa

$= 500$ hPa

$P = 500$ mb

Atmospheric pressure

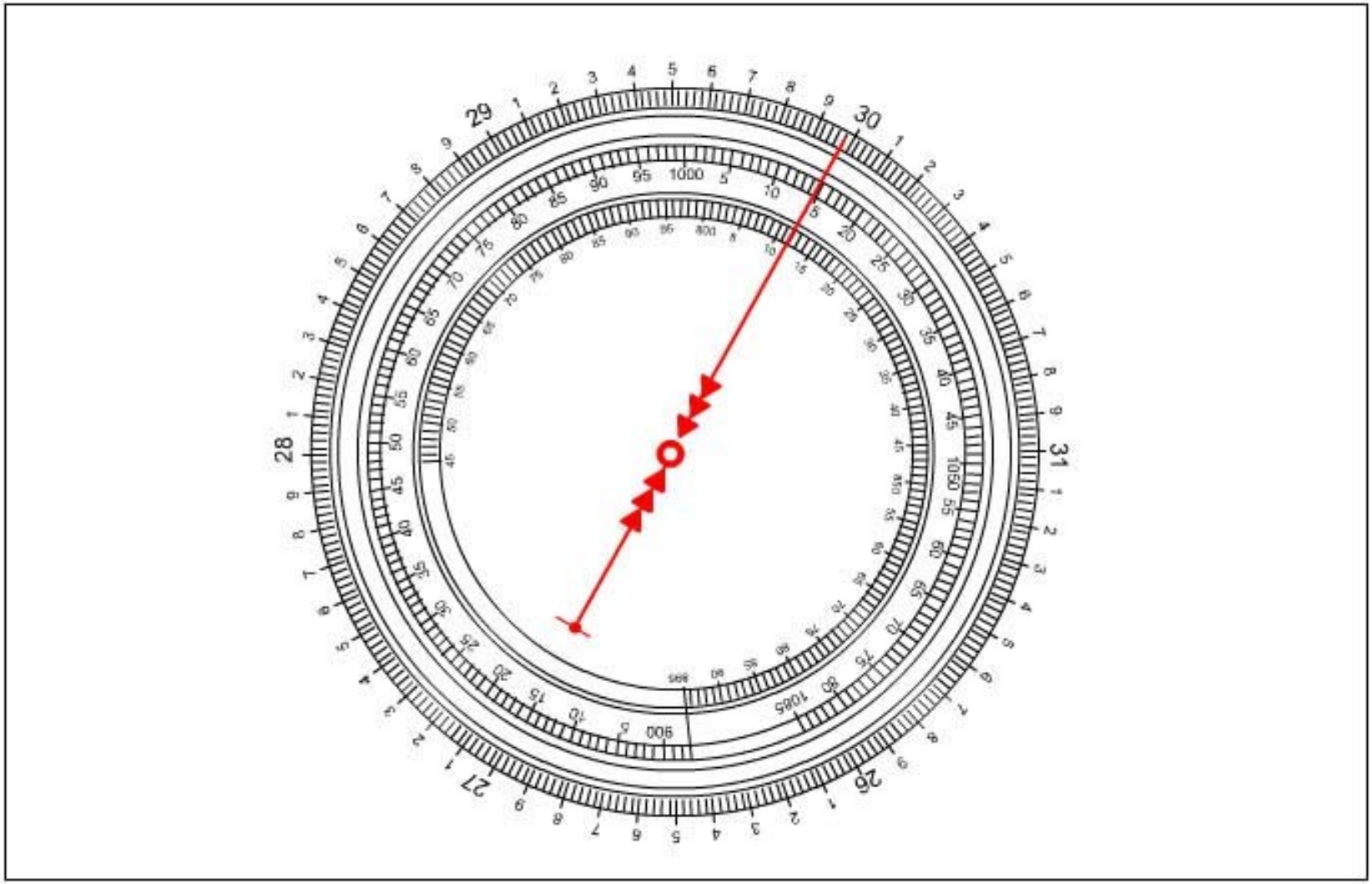
- Variations in atmospheric pressure are analyzed extensively in preparing weather forecasts.
- Methods of measuring atmospheric pressure.
  - Mercurial barometers measure the pressure by the height of a column of mercury in an evacuated tube and are not used operationally.


Mercurial Barometer
29.92"
AIR COLUMN

Atmospheric pressure

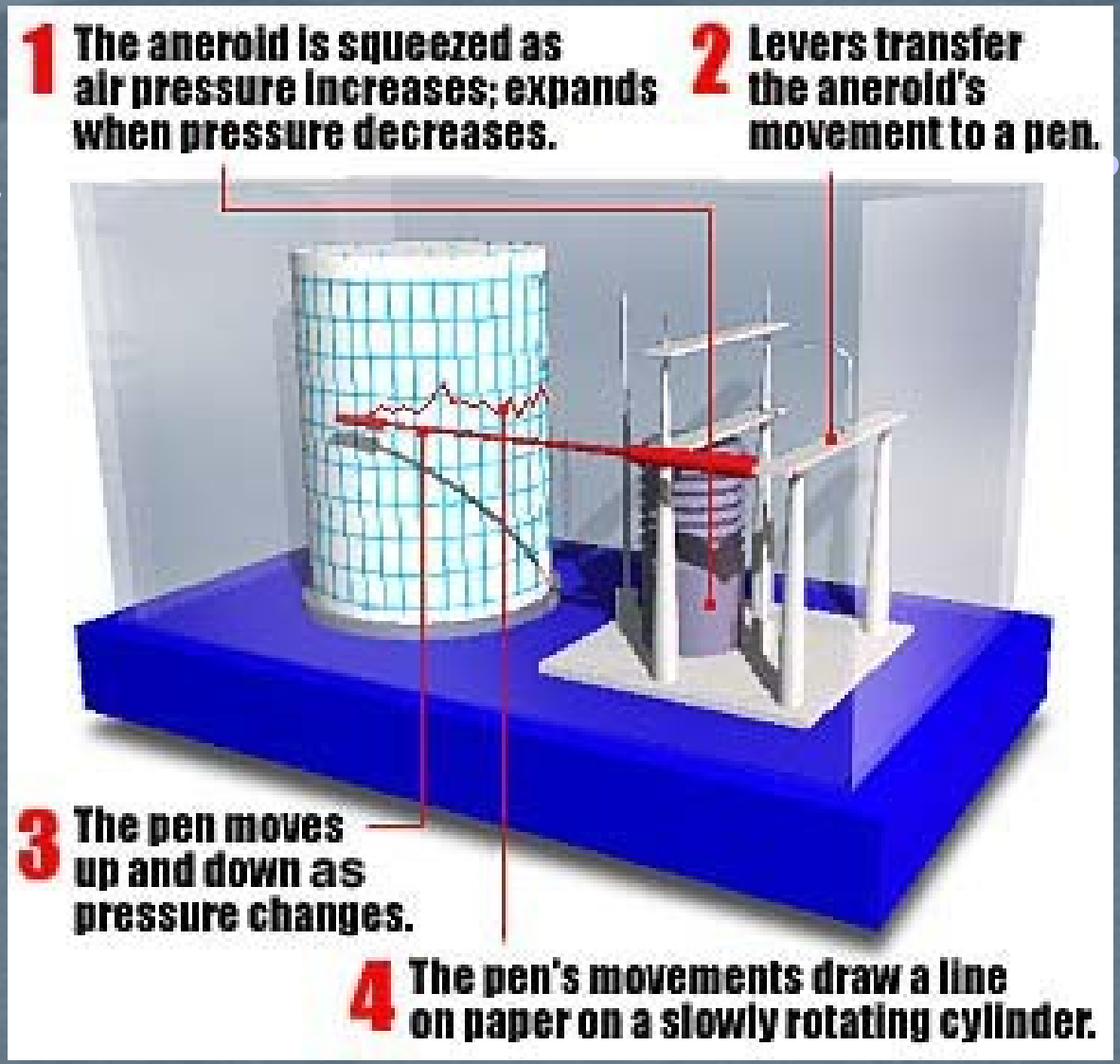
- Methods of measuring atmospheric pressure. (cont)
  - Aneroid barometer
    - Most common type of home barometer which contains no fluid
    - Inside the instrument is a flexible metal box called an aneroid cell
    - Air is partially removed from this tightly sealed cell, so that it is very sensitive to small changes in external air pressure

http://www.mid-c.com/manmar/The_Bel



Atmospheric pressure

- Methods of measuring atmospheric pressure. (cont)
  - Aneroid barometer
    - The box expands and contracts, and the changes in size are amplified and transmitted to a needle, which points to the current pressure on a scale.


1 The aneroid is squeezed as air pressure increases; expands when pressure decreases.
2 Levers transfer the aneroid's movement to a pen.
3 The pen moves up and down as pressure changes.
4 The pen's movements draw a line on paper on a slowly rotating cylinder.

USA Today

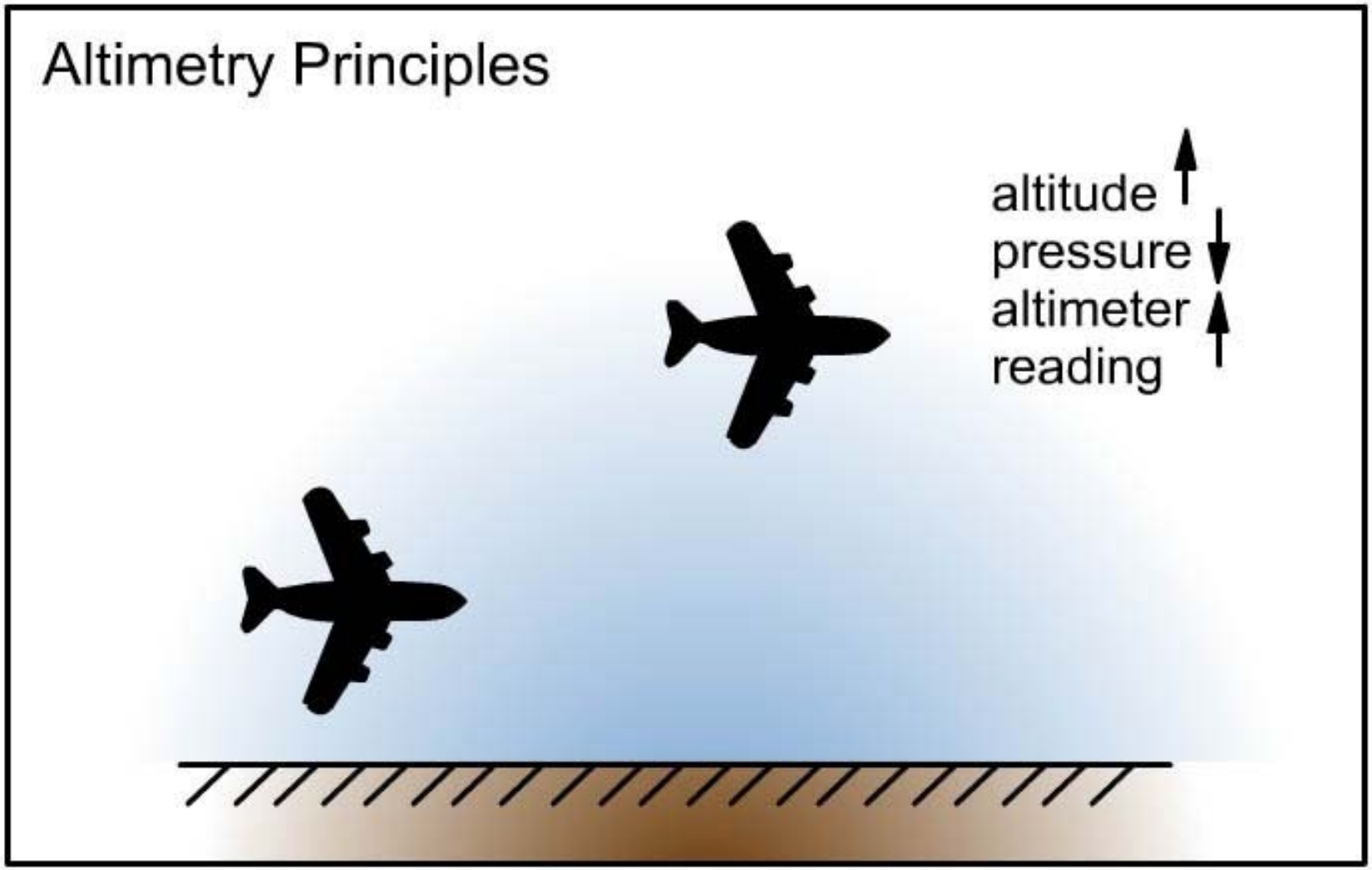
Atmospheric pressure

- Methods of measuring atmospheric pressure. (cont)
  - Altimeter
    - A type of aneroid barometer
    - Measures pressure but indicates altitude (meters and feet) above mean sea level (MSL)

Atmospheric pressure

- Methods of measuring atmospheric pressure. (cont)
  - Altimeter
    - Altitude is inversely proportional to measured pressure
      - As the pressure decreases, the altitude increases. (Pressure naturally decreases with height)
      - A 1 inch decrease in pressure equals approximately a 1,000 foot increase in altitude (within a few thousand feet of sea level).

Altimetry Principles



Atmospheric pressure

- Methods of measuring atmospheric pressure. (cont)
  - Altimeter
    - Calibrated according to the Standard Atmosphere
      - See Skew-T diagram
      - Any deviation from standard will cause the altimeter reported altitude to be inaccurate.

Atmospheric pressure

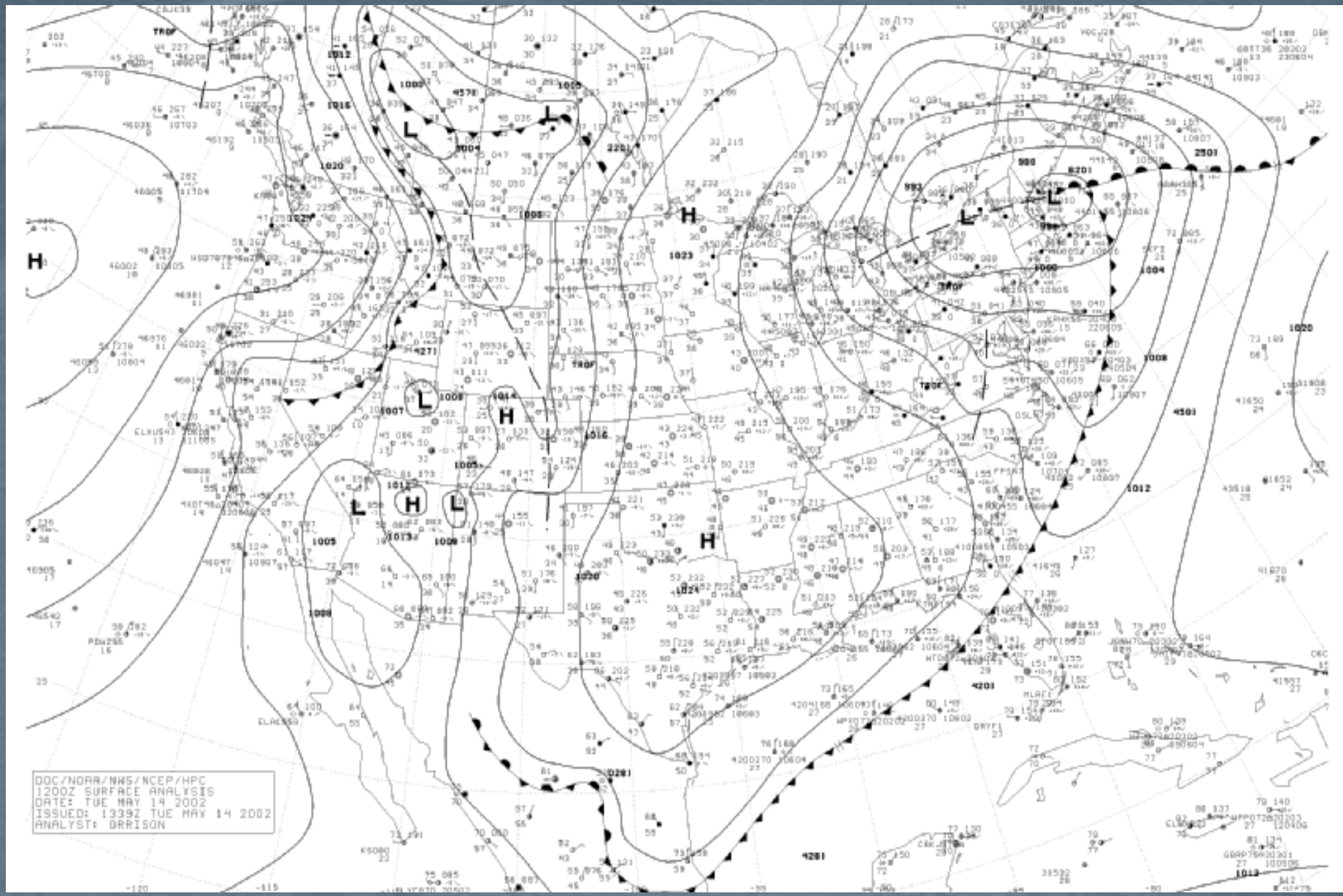
- Methods of measuring atmospheric pressure. (cont)
  - Digital barometer
    - Provides a digital readout of the altimeter setting and station pressure.
    - Displayed to the nearest .001 inch (or .1 mb)

Atmospheric pressure – Depicting pressure on charts

- Constant height surfaces – the height everywhere on the chart is the same.
  - Surface pressure analysis – the constant height is mean sea level.
    - Measured surface pressures (station pressure) are corrected to sea level.
    - Corrections are made using the R factor.
    - Uncorrected surface charts would show low pressure in areas of higher terrain (i.e. Denver, CO)

Atmospheric pressure – Depicting pressure on charts

- Depicting pressure on charts
  - Constant height surfaces (cont)
    - Two examples of constant height charts
      1. Surface chart
         - » Isobars – lines of equal pressure every 4 mb
         - » Low and high pressure centers are marked
         - » Constant height (sea level), changing pressures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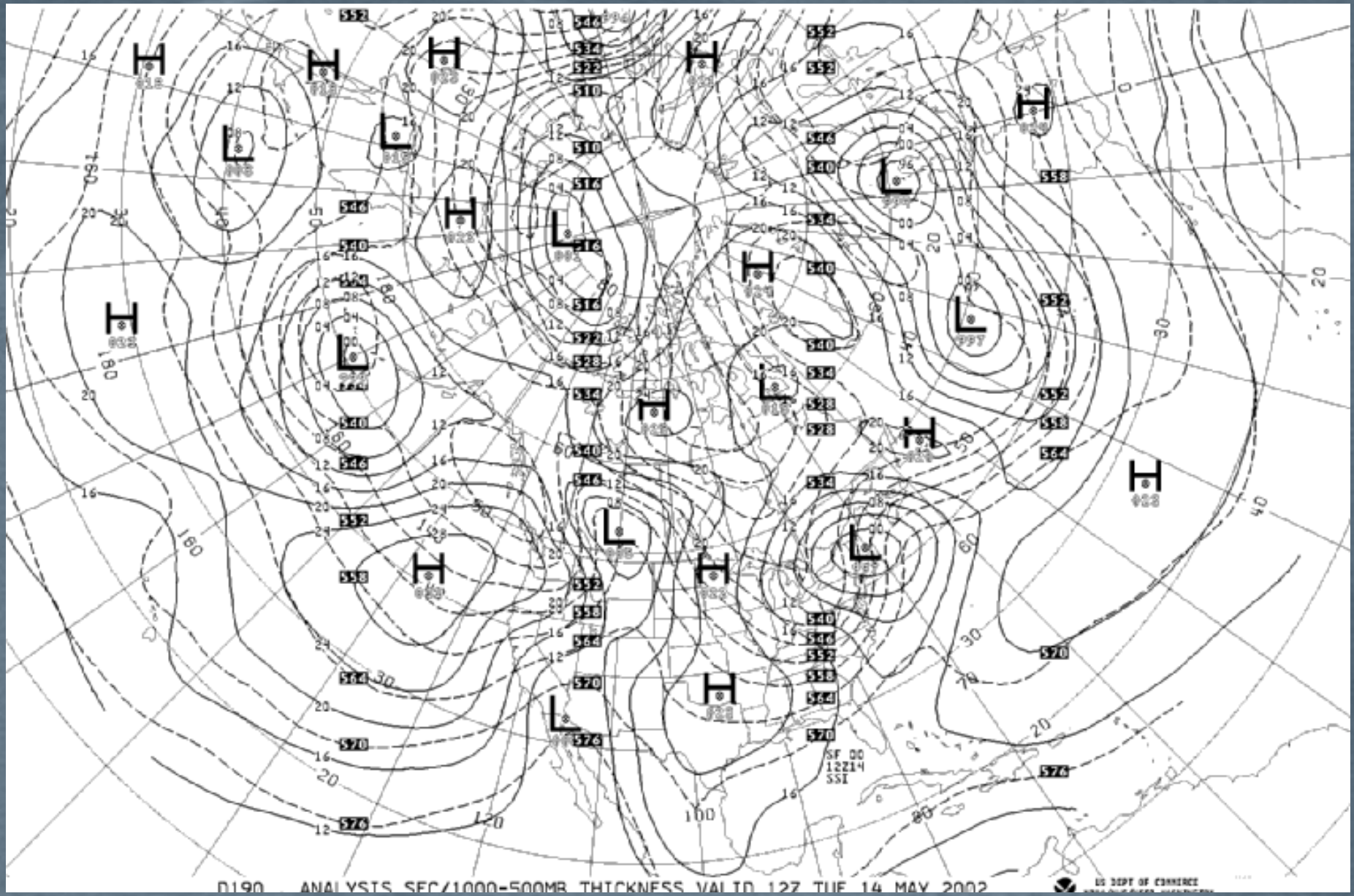
ISSUED: 1339Z TUE MAY 14 2002
ANALYST: ORRISON

Atmospheric pressure – Depicting pressure on charts

- Constant height surfaces (cont)
  2. Sea Level Pressure Chart
     - Computer generated chart
     - The solid lines are surface isobars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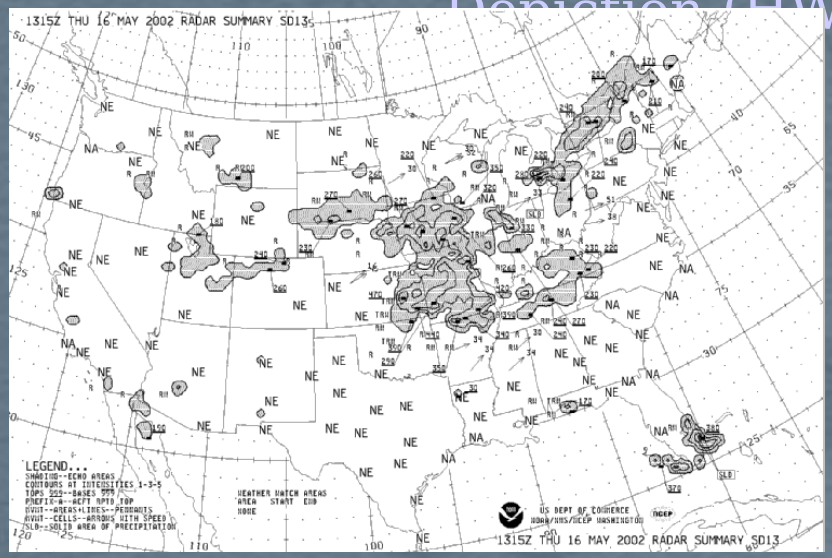
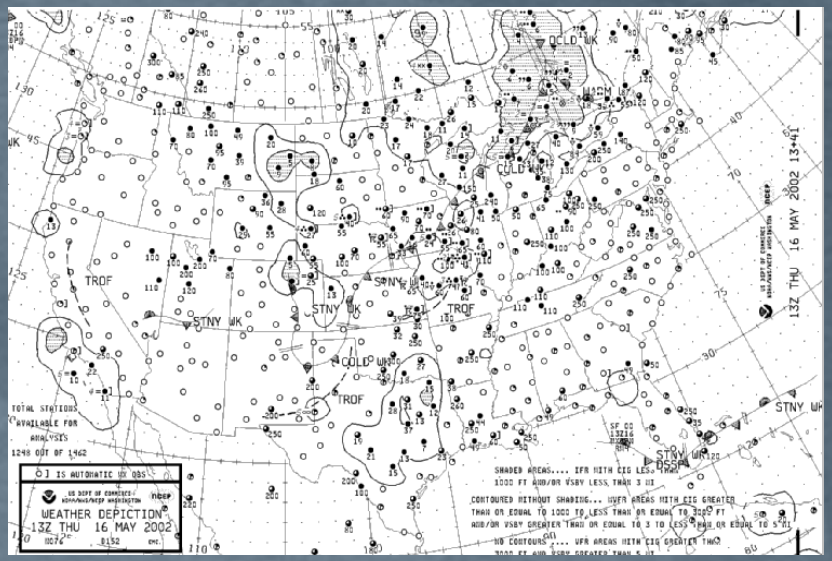
Atmospheric pressure – Depicting pressure on charts

- Constant height surfaces (cont)

3. Other examples of constant height charts are the Radar Summary and Horizontal Weather Depiction (HWD)





Atmospheric pressure – Depicting pressure on charts

- Constant pressure surface – the pressure everywhere on the chart is the same (i.e., 850, 700, 500, 300, 200 mb charts)
  - Contour lines connect points of equal height.
  - Heights are expressed in decameters

Atmospheric pressure – Depicting pressure on charts

- Constant pressure surface (cont)
  - Standard interval depends upon the level analyzed
    - 120 m on 300 mb charts
    - 60 m on 500 mb charts
    - 30 m on 700 and 850 mb charts

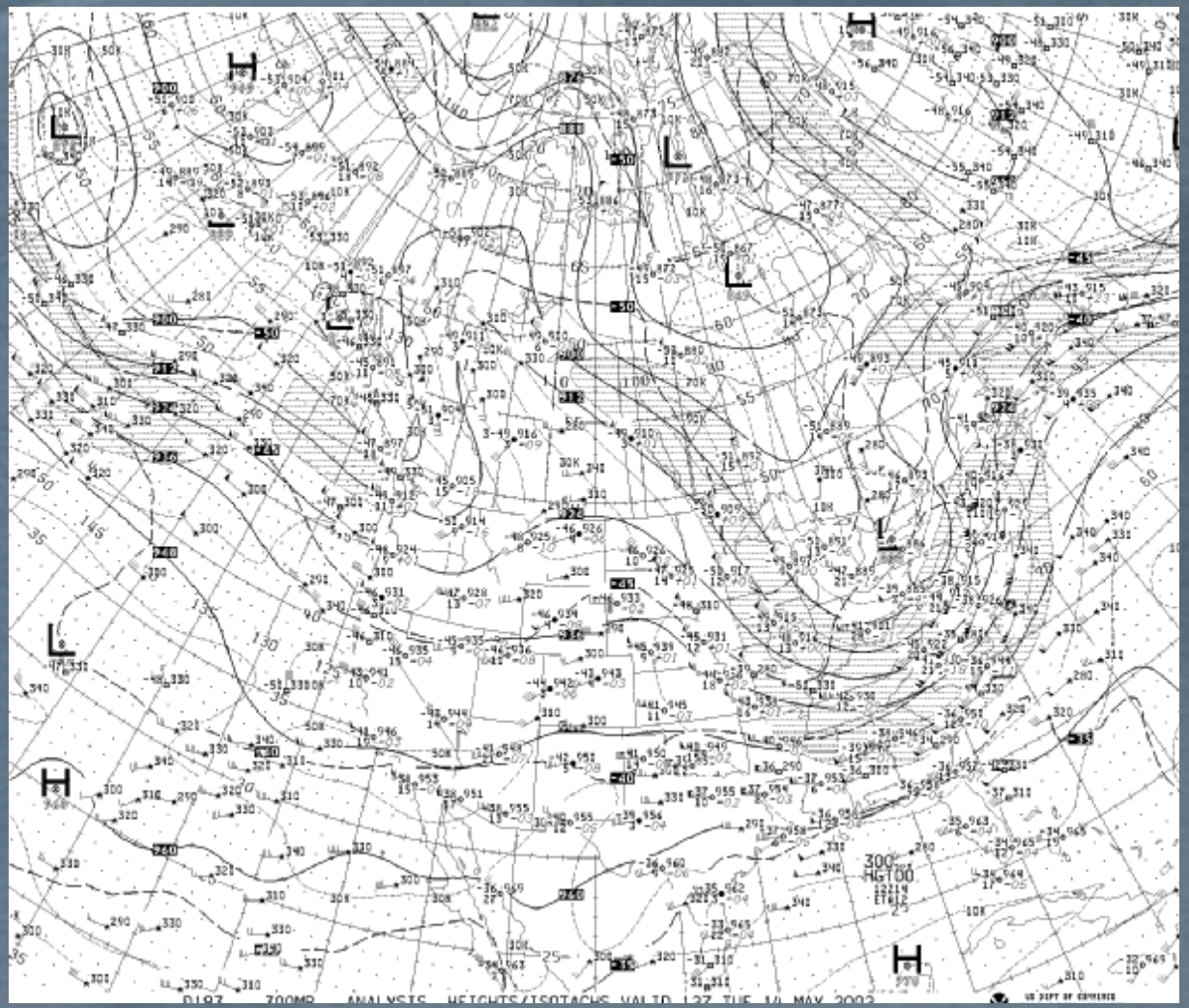
Atmospheric pressure – Depicting pressure on charts

- Constant pressure surface (cont)
  - Standard height values:
    - 300 mb – 9,164 m – 30,065 ft (~30,000 ft)
    - 500 mb – 5,574 m – 18,289 ft (~18,000 ft)
    - 700 mb – 3,012 m – 9,882 ft (~10,000 ft)
    - 850 mb – 1,457 m – 4,781 ft (~5,000 ft)
    - 925 mb - 762 m – 2,500 ft
    - 1000 mb – 111 m – 364 ft (close to the surface)

Atmospheric pressure – Depicting pressure on charts

- Examples of constant pressure charts:
  - 300 mb
    - Solid lines are contours
    - Dark (large) dashed lines are isotherms.
    - Smaller (light) dashed lines are isotachs (lines of constant wind speed).

300 mb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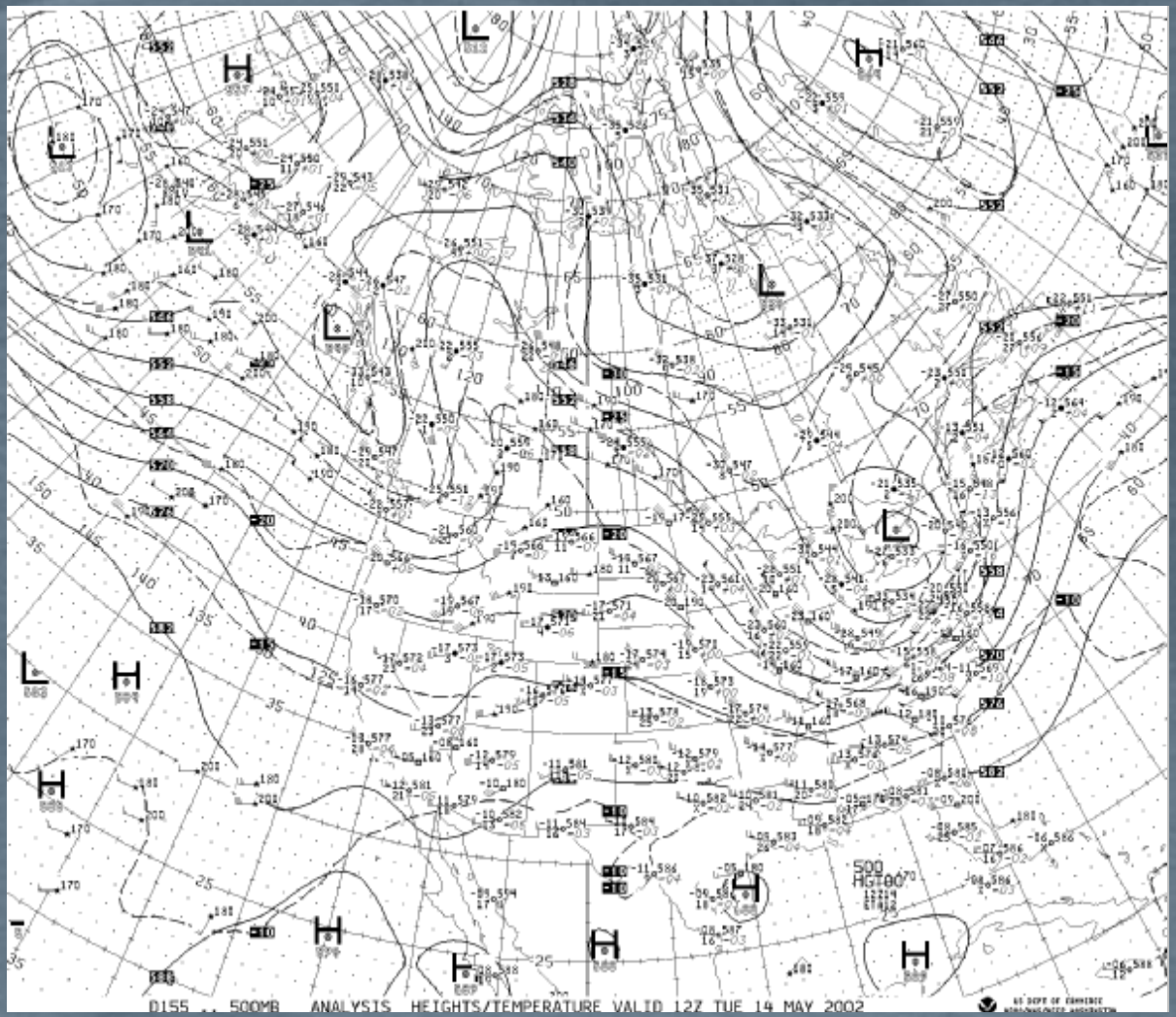
Atmospheric pressure – Depicting pressure on charts

- Examples of constant pressure charts:
  - 500, 700 and 850 mb
    - Solid lines are contours
    - Dashed lines are isotherms

500 mb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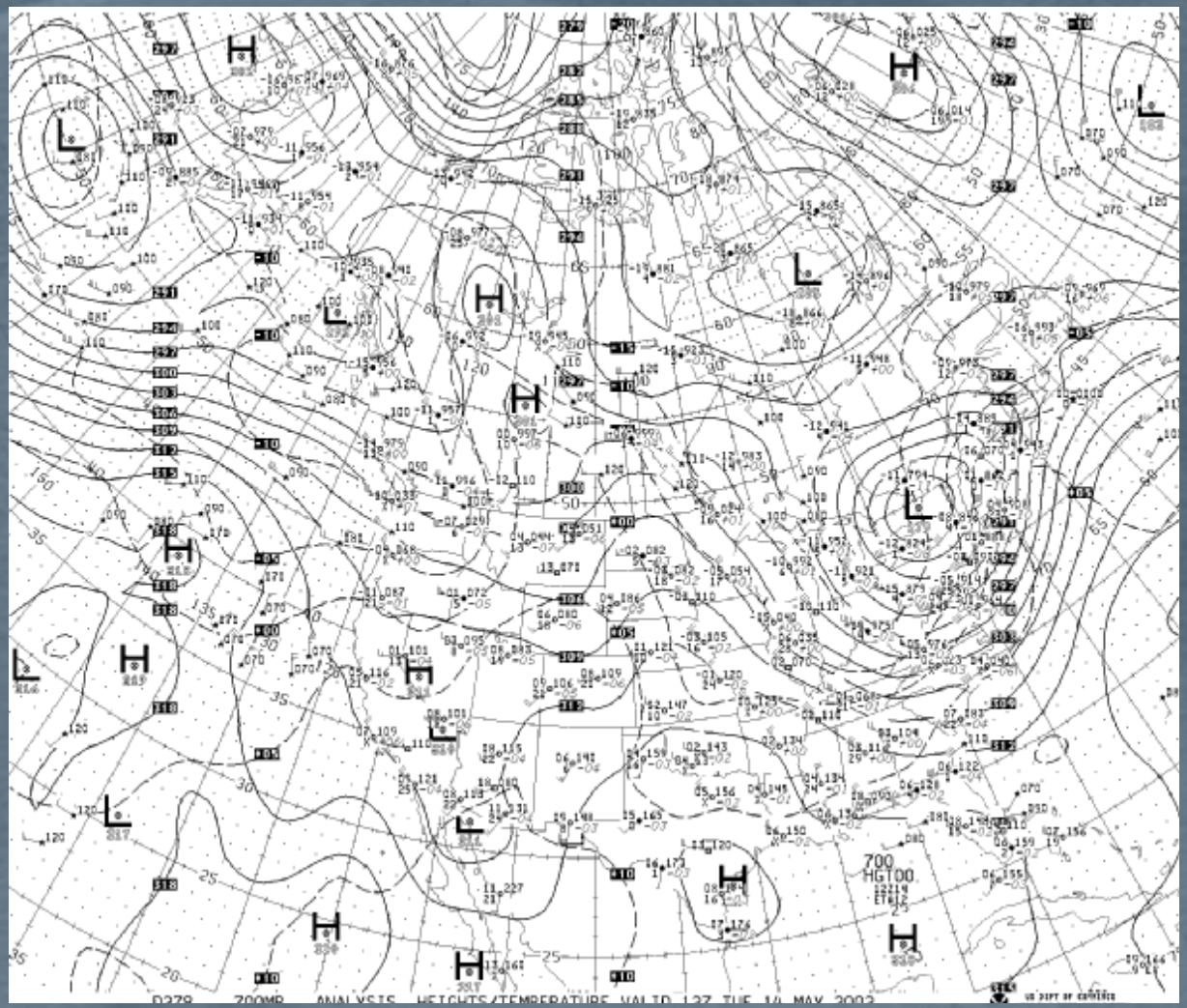
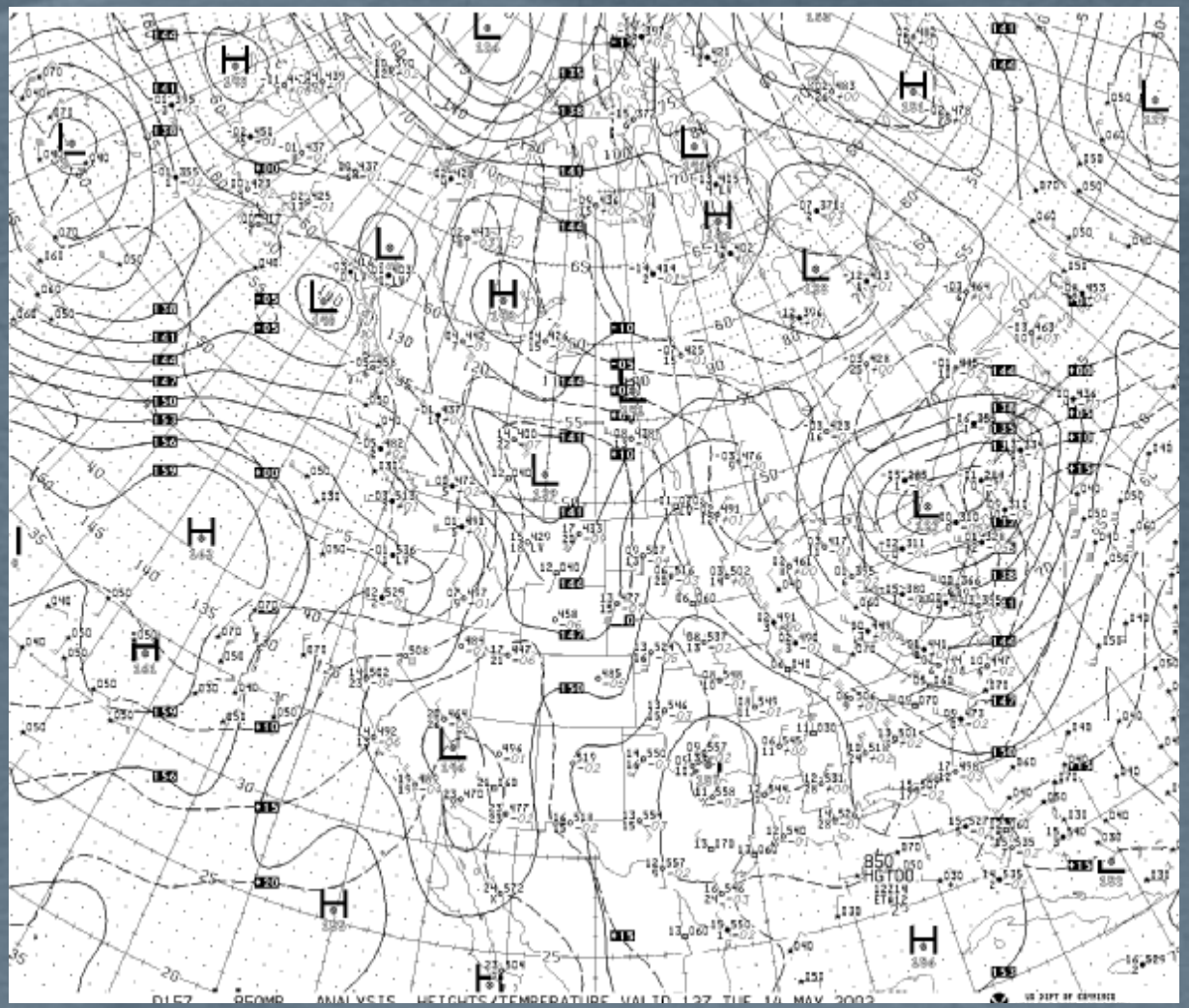
700 mb



850 mb

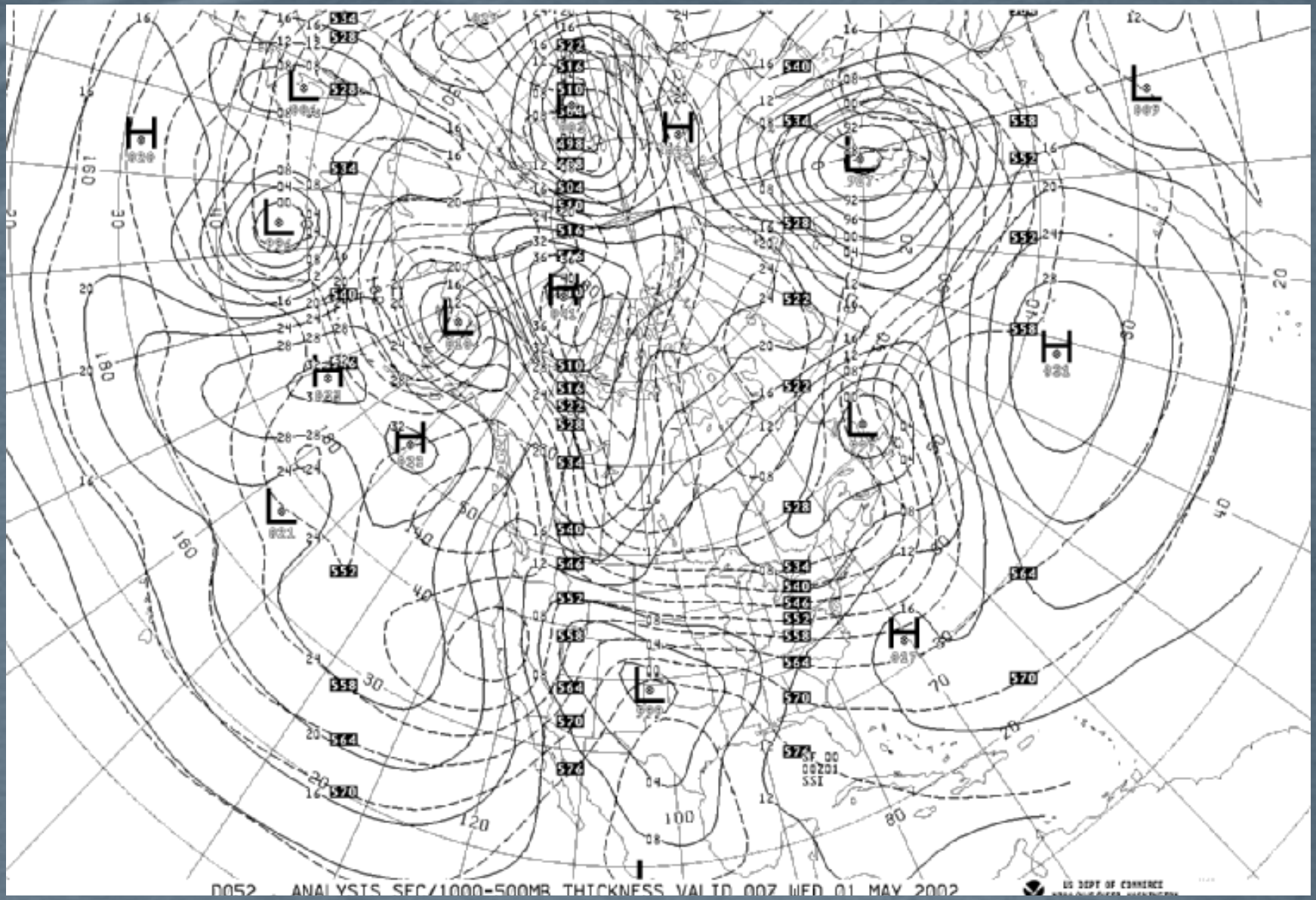


Atmospheric pressure – Depicting pressure on charts

- Combination of a constant height and constant pressure chart:

  1000-500 mb Thickness Chart/Sea Level Pressure Chart

  - Computer generated chart
  - The values of thickness are computed using the height of two pressure levels (i.e. 1000-500 mb thickness)
  - Thickness isopleths (lines of constant value) are depicted as dashed lines on the 1000-500 mb thickness chart.
  - The solid lines are surface isobars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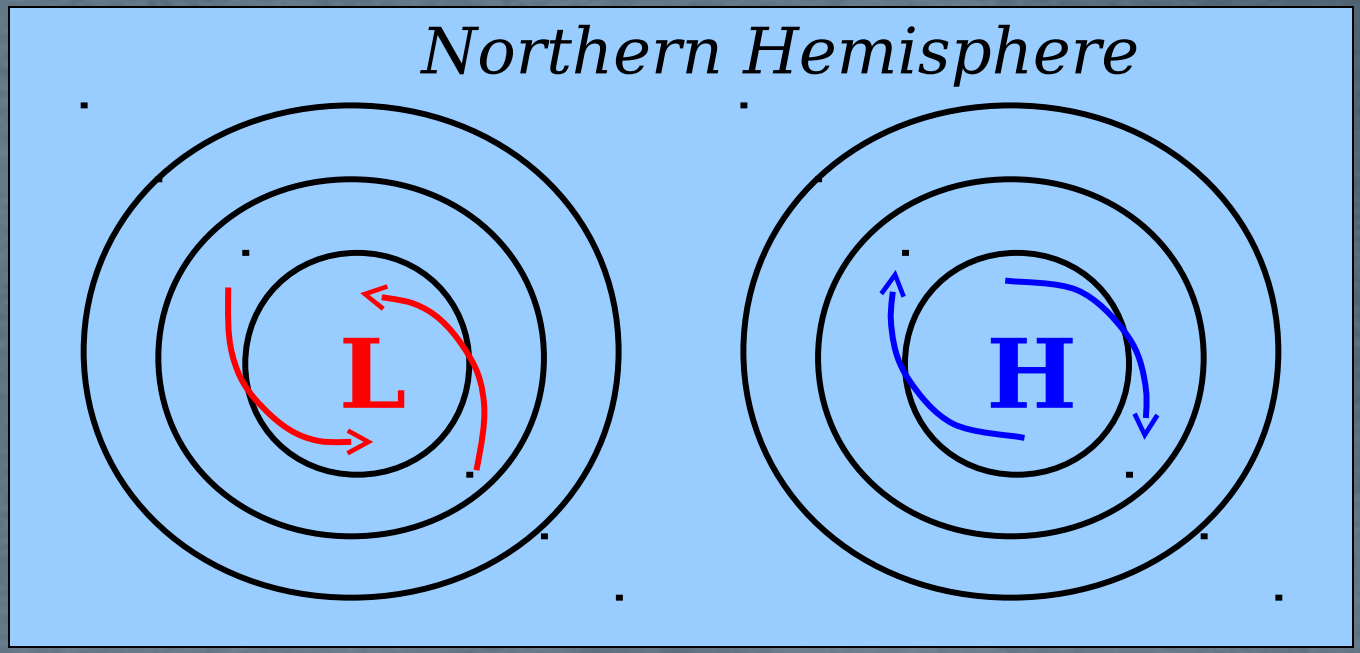
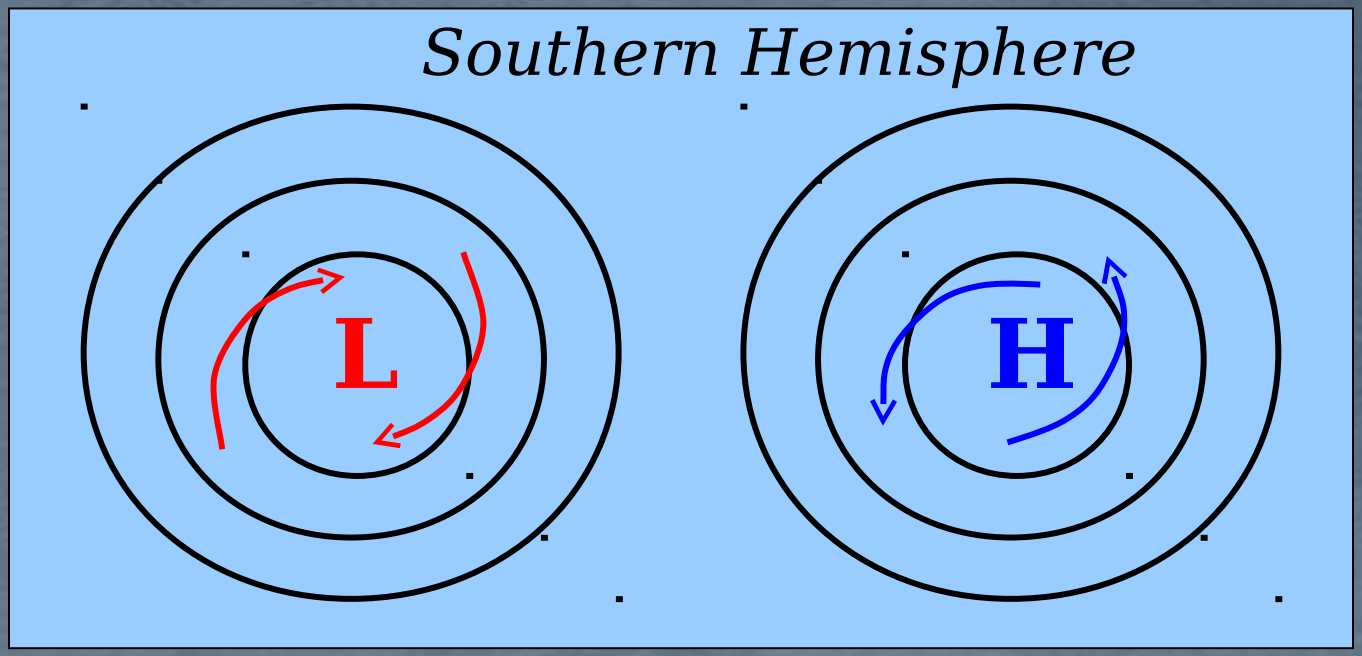
Atmospheric pressure – Depicting pressure on charts

- Buy's Ballot's Law
  - Used to determine wind direction using contours or isobars.
  - Northern Hemisphere:
    - With the wind to your back, lower pressure (or heights) will be to your left in the Northern Hemisphere
    - The flow is cyclonic (counterclockwise in Northern Hemisphere) around low pressure systems and troughs.
    - The flow is anti-cyclonic (clockwise in the Northern Hemisphere) around high pressure systems and ridges.
- Assumptions: This rule is not used in the tropics. This rule assumes that flow is parallel to the weather map contours. This rule is not used for actual winds near the surface. (Reasons will be discussed later in the course.)

Determining Wind Direction Using Buys-Ballots Law

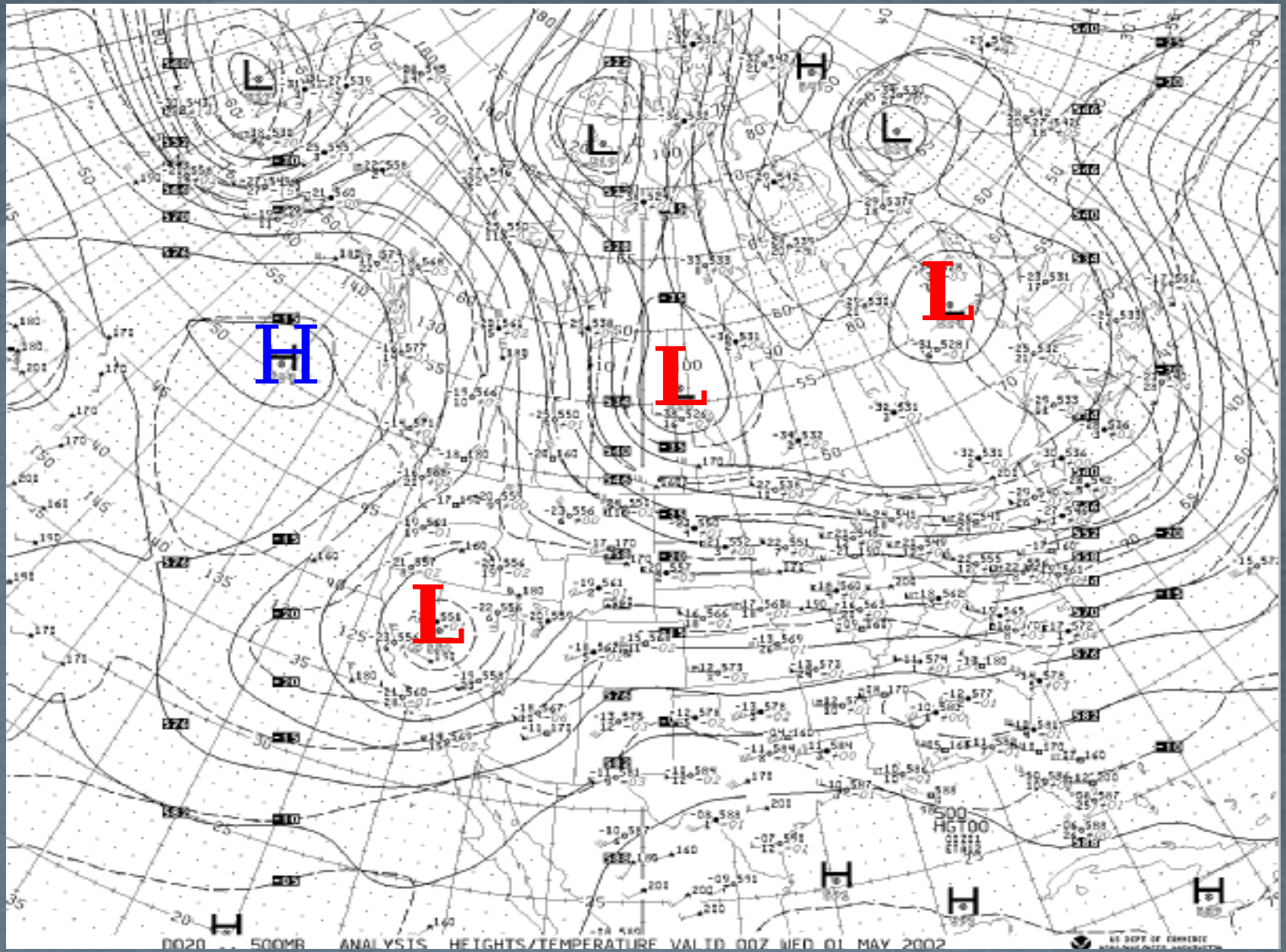


Determining Wind Direction Using Buys-Ballots Law



Atmospheric pressure – Depicting pressure on charts

- Typical features on constant heigh t charts :
  - Low center – a point at which the pressure (height) is a minimum.
  - High center – a point at which the pressure (height) is a maximum.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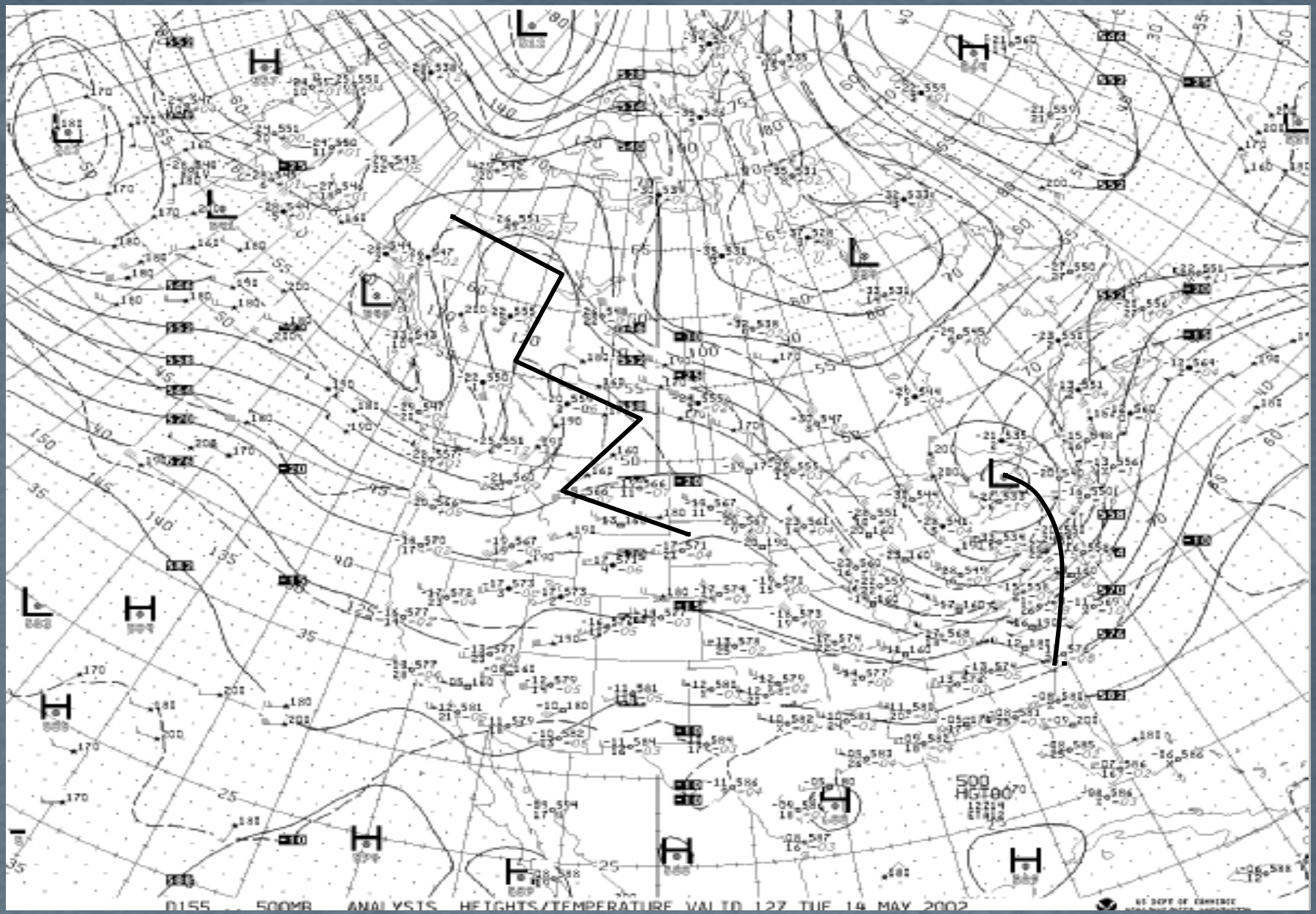
Atmospheric pressure – Depicting pressure on charts

- Typical features on constant height charts:
  - Troughs – elongated areas of lower pressure (height) (more in Dynamics I)
    - Pressure is lower along the trough axis than on either side of the trough axis.
    - Winds turn cyclonically in a trough.
  - Ridges – elongated areas of higher pressure (height)
    - Pressure is higher along the ridge axis than on either side of the ridge axis.
    - Winds turn anticyclonically in a ridge.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Atmospheric pressure

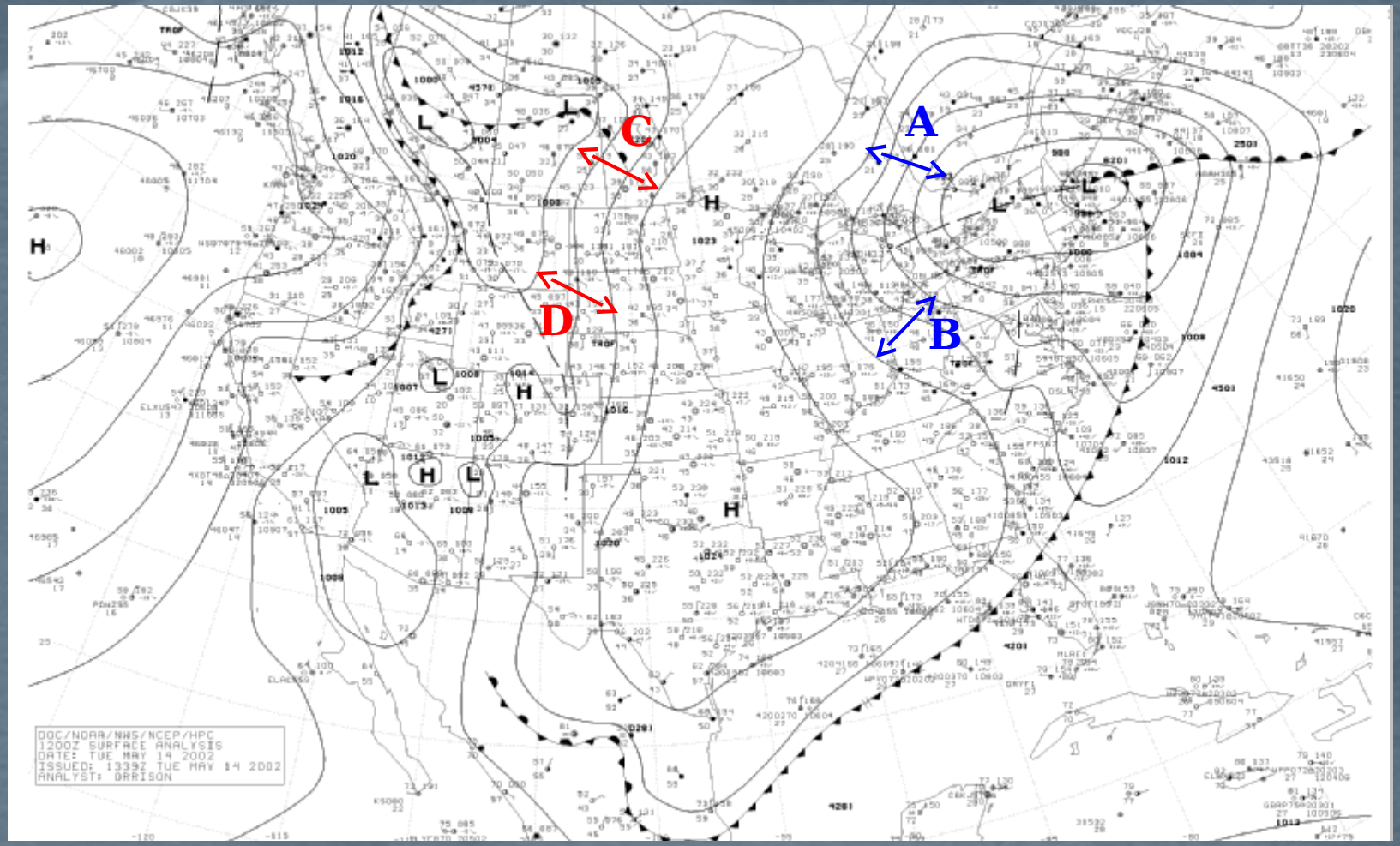
- Gradient – change of some quantity over a distance perpendicular to an isopleth.
  - Pressure gradient (horizontal)
    - Pressure gradient is the change of pressure per unit distance perpendicular to the isobars (Δn)

$$PG = \frac{\Delta P}{\Delta n}$$

Atmospheric pressure

- Gradient – Pressure gradient cont.
  - PG is directly proportional to the change in pressure
    - The greater the change in pressure over a given distance (more closely spaced isobars), the greater the pressure gradient.
    - The smaller the change in pressure over a given distance (more widely spaced isobars), the smaller the pressure gradient.

Dependence of Pressure Gradient on Isobar Spacing



Atmospheric pressure

- Gradient
  - Height gradient – equivalent to pressure gradient on constant pressure surfaces.
    - Height gradient is the change of height per unit distance (perpendicular to the contours).

$$HG = \frac{\Delta P}{\Delta n}$$

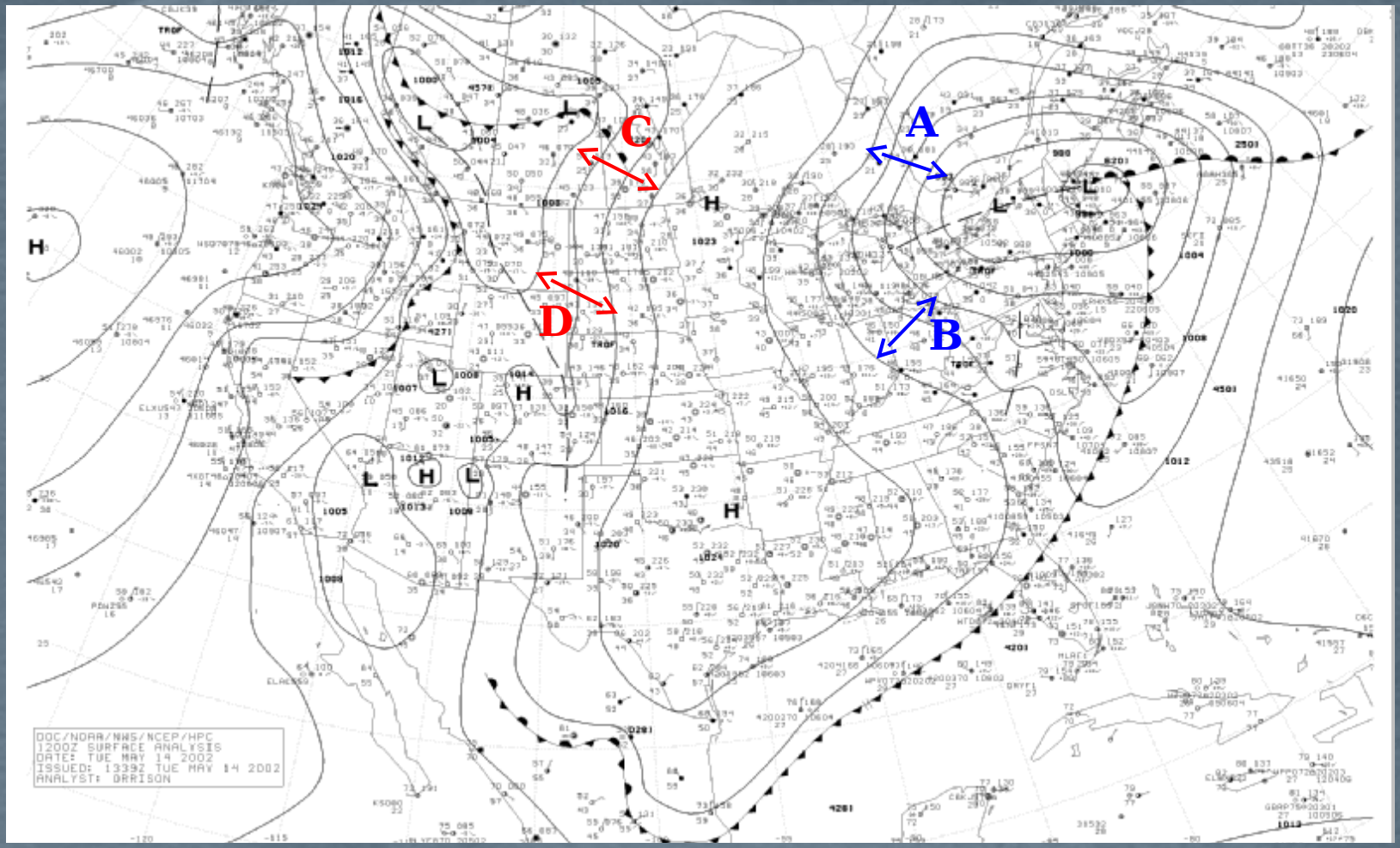
    - HG is directly proportional to the change in height of the pressure surface.
    - The gradient vector is oriented parallel to Δn and points in the direction of lower pressure or heights.

Atmospheric pressure

- Gradient
  - Gradient terminology
    - Small isopleth spacing = tight or strong gradient
    - Large isopleth spacing = loose or weak gradient

Atmospheric pressure

- Gradient
  - Pressure (height) gradient is responsible for initiating the winds.
    - The wind speed is directly proportional to the pressure (height) gra dient.
    - The wind speed is inversely proportional to the isobar (height) spac ing.
- Gradients are found for other variables. (We'll discuss temperature gradient in Objective d.)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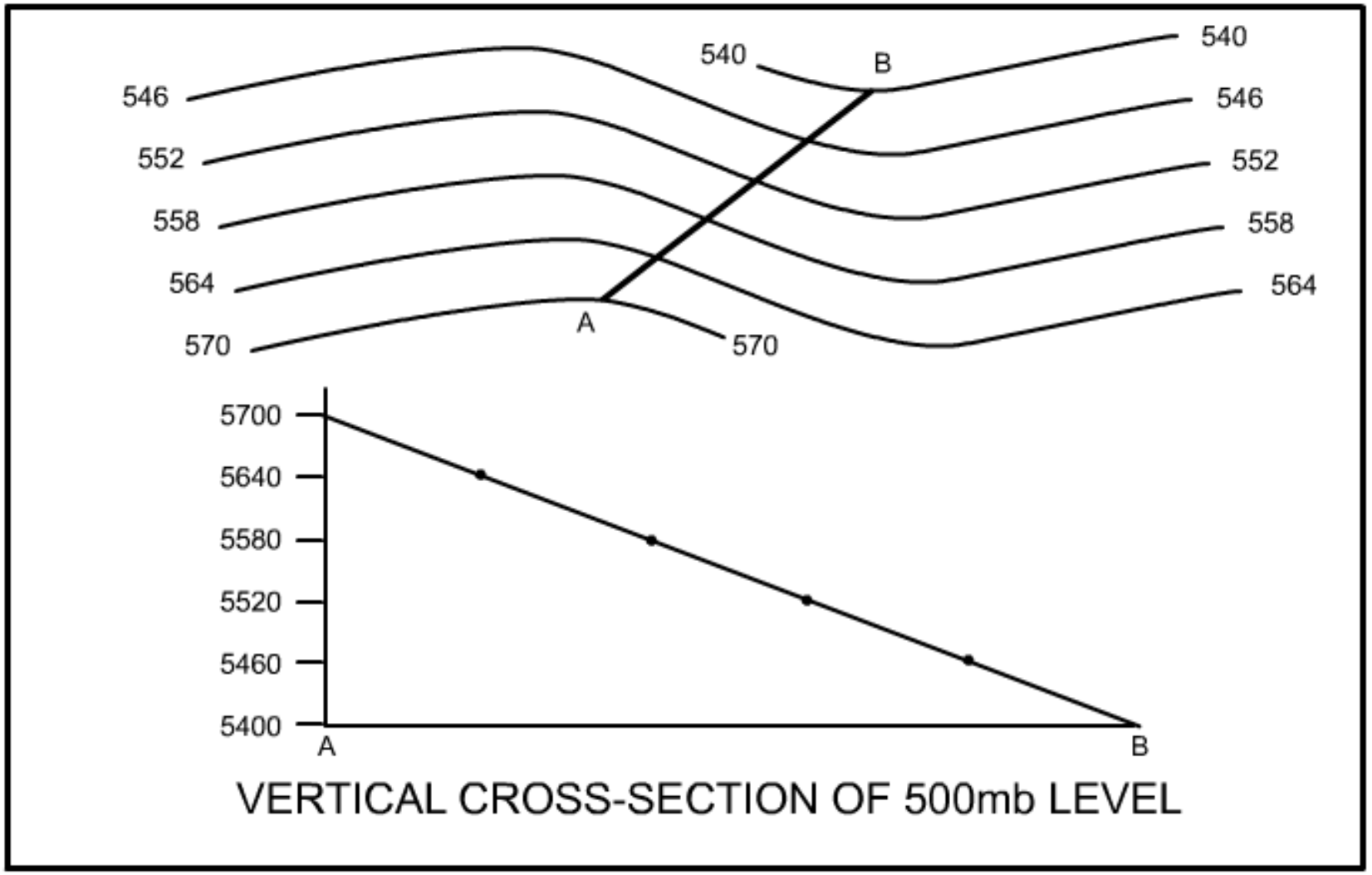
ANALYST: ORRISON

Atmospheric pressure

- Vertical cross section
  - Shows slope of a constant pressure surface along a horizontal line. Similar to a topographic map.
  - Vertical slice of the atmosphere (more in Dynamics)
  - The closer the contours are, the steeper the slope, hence, the stronger the wind speed.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VERTICAL CROSS-SECTION OF 500mb LEVEL

Atmospheric pressure

- Vertical cross section
  - Procedure
    - Select the line along which to do the cross section and mark it on the chart.
    - Set up axes (horizontal axis is the line drawn on a chart, vertical axis is the height of the pressure surface).
    - Determine height values along the line.
    - Plot the height of the pressure level vs the horizontal position.
    - Connect the plotted points.

Atmospheric pressure

- Vertical cross section
  - The slope of the cross section is directly proportional to the wind speed only if the cross section is oriented parallel to the gradient vector, thus perpendicular to the wind (more in Dynamics)

Altimetry

- The vertical cross section shows the path an aircraft would take if a pilot flew according to the altimeter.
  - An altimeter measures the pressure and reads as altitude.
  - The altimeter is only an estimate of the true altitude.
  - Planes flying according to altimeters are flying along a constant pressure surface.
  - Because the altitude of a pressure surface varies, the altimeter must be constantly corrected to maintain flight level.

Altimetry

- Altimeter settings.
  - Corrections made to altimeters to adjust for non-standard atmosphere.
  - The type of setting used depends on the altitude and location of the flight.
  - The correction is actually the altimeter setting produced at the weather station and relayed to the pilot.
  - The altimeter setting makes the aircraft's altimeter read closer to the actual altitude (but still is only an estimate).

Altimetry

- Altimeter settings.
  - Types of altimeter settings
    - QNE – always set at 29.92 inches (standard sea level pressure).
      - Used by all aircraft above 18,000 feet MSL in the CONUS (the value is different in other parts of the world).
      - Altimeter reads the height above the standard sea level (MSL)
      - All aircraft with the same altimeter reading will be flying at the same level.

Altimetry

- Altimeter settings.
  - Types of altimeter settings
    - QNH – Set to the corrected sea level pressure of the station.
      - Used for takeoffs and landings and below 18,000 feet in the CONUS (the value is different in other parts of the world).
      - Altimeter reads height above sea level.
      - The altimeter reads the station elevation when at ground level.

Altimetry

- Altimeter settings.
  - Types of altimeter settings
    - QFE – set to the actual surface (station) pressure
      - Used overseas at stations close to sea level (i.e. Netherlands)
      - Altimeter reads 0 feet when at ground level.

- Assign Review Exercise in WB-100
- Administer and evaluate Appraisal 102d. Give the written test at the end of the unit.